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Proposal to Investigate Cure of Vibration Difficulties with Optical Equipment

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TASK ABSTRACT

A two phase investigation is proposed.

Phase 1

It is proposed that customer equipment be analysed for vibration difficulties caused by building motion and by internal equipment resonances. During the investigation certain dynamic tests may be conducted and measurements made in both amplitude and frequency. This will be related to anticipated higher resolution and magnification requirements as well as to current needs. A report will be prepared on the extent of the vibration problems with respect to the five instrument types chosen during the course of the work.

Phase 2

This phase includes a detailed analysis of the equipment determined in Phase 1 to have significant vibration problems. The detailed analysis will cover the extent and type of fix required to meet the current and future requirements on the selected equipment and will include a trade off analysis on cost versus fix versus extent of improvement expected. A typical cure will be devised, applied and demonstrated on a selected item of equipment. Specifications will be generated to provide vibration design criteria for future equipment. A recommendation will be made as to the practical vibration environment for high resolution equipment.

Phase 1 can be accomplished for an estimated total CPFF Price [redacted] including a fee [redacted] STAT
Phase 2 will be estimated as a part of the final report on Phase 1.

1.0 Introduction

As the magnification of optical systems necessarily becomes higher to accommodate the ever finer resolutions, the sensitivity to vibration disturbance increases. The disturbance not only causes operator eye fatigue but also limits his ability for precision measurement and analysis. The extent to which vibration disturbance limits measurement (pointing) accuracy on each equipment will be investigated. In addition, those equipments which have obvious vibration difficulties causing operator eye fatigue will be reviewed for improvement. Note that there may be some equipments for which there is no practical cure of vibration due to their inherent design.

Artificially induced vibration will be used for the investigation, as well as that intrinsically present in the building itself. Vibration input level will be correlated to the observed difficulty so that the cure can be evaluated for possible future higher input vibrations as well as the existing levels. Attempt will be made to correlate these physical motions with operator difficulties and/or pointing accuracy. Observations will be made, either during building quiet times or by special isolation, to get a standard of excellence on each equipment for comparison to performance under vibration before and after the cure.

It is proposed that contractor personnel will be provided access to the customer's facility so that presently installed equipment of concern can be investigated in place. The contractor will provide the necessary instrumentation for both the excitation and measurement of vibration input and the observation of response. The customer is to provide operator assistance and demonstration to insure the contractor's understanding of the practicalities involved in the use of the several equipments so as to judge the appropriateness of possible cures.

2.0 Technical Discussion

Vibration problems with equipments can result from self-induced vibration as well as external input. In both cases the structural design is such that it responds in a disturbing or damaging manner to vibratory excitation.

2.1 Eye Vs. Image Motion Problem

On those equipments designed for visual observation, the difficulties are typical of one facet of the eye-image problem which is one of the most difficult human-to-machine interfaces. The presentation of images to the eye for detail study without causing eye fatigue is most involved. In the past the major sins have been in the design of the optics, namely the size of the pupil entrance, the brightness of the image, and the eye relief provided. All of these have long since been solved by optical designers and are not of consideration here. However, the eye, with its automatic focus and diaphragm and its ability to follow image motion, is very forgiving of most vibration problems. When difficulty arises, one has exceeded the ability of the eye to correct for these effects or they are so near to the limit of the eye's ability that extreme fatigue occurs. Improper structural design of high magnification optical systems results both in transverse image motion and variable image focus. If the frequency of the transverse motion is low enough the eye will follow it. If the frequency of the variation in focus is slow enough, the eye can correct. Both of these effects must occur at rates well below two cycles per second to avoid eye fatigue. This means that optical systems with magnifications of 40x and higher must have their structures carefully designed to avoid damaging image motion from vibration disturbance. Of course, the fundamental problem is presenting an image to the eye that it cannot interpret. It must never be forgotten, as one can easily get lost in the intricacies of the vibration analysis.

2.2 Building Vibrations

The vibration disturbances to buildings are from two sources, natural and man-made. External man-made sources are usually traffic, railroads, and heavy equipment such as pumps, compressors, rock crushers, etc. Internal sources are most often from forced draft air conditioning systems and their associated fans and compressors. Note that air pressure pulses of extremely low levels can produce considerable wall deflection, resulting in building vibration. Motions of closed doors are extremely good indicators of air conditioning induced vibrations of this type.

2.2.1 Natural Vs. Man-Made Sources

Natural sources are called microseisms. They have been correlated to storms, ocean waves, river flow, etc. The amplitudes of both natural and man-made vibration disturbances are usually in the same range of 0.2 to 25 microns peak to peak. However, man-made disturbance usually has a frequency of 5 Hz or higher while microseisms generally have frequencies below 2 Hz down to 1/10 Hz or less.

2.2.2 Building Vibration Response

Building floor vibration amplitudes are ordinarily in the 0.2 to 4.0 micron range peak to peak. As they are almost entirely caused by man-made sources, and the natural frequency of floor decks are in the same range as well, the dominant vibration frequencies are usually in the 10 to 20 Hz range. From the foregoing and the already available vibration survey data, the building can be considered reasonably quiet, having a maximum peak to peak amplitude in the 1 micron range and dominant frequencies near 20 Hz. Therefore, it should be feasible to operate high magnification optical systems within it if proper equipment design techniques are followed.

2.3 Image Motion Caused by Rocking of Optics

Note that the image motion of concern in visual observation equipments is due to the relative motion between the object and the optical system, resulting in transverse image motion. Usually the overall motion of the equipment is of such low amplitude that it is virtually undetectable by the operator. Only vibratory motions magnified by the optical system can cause difficulty in viewing. These, therefore, are relative vibratory motions within the device itself. Also note that the depth of focus probably exceeds the axial motion amplitude of the optics so focus variation is unlikely to be a problem. Rather, the problem is very similar to that of long focal length camera design, namely the damaging transverse image motions are caused bv rocking vibrations of the optics. The effective optical lever arm (x40 or more) sweeps the image transversely over long apparent excursions from the almost imperceptible rotary motions of the optics.

3.0 Discussion of Investigation

As noted, the damaging relative motion from vibration is rotational about axes perpendicular to the optical axis. Many equipment designs fail to provide proper torsional stiffness in the optics support and even minor vibration input causes disturbing image motion. The investigation then is concerned with discovering the dominant vibration mode that causes the image motion and then locating the major mass-spring system that allows the motion. The assumption is that simple joint looseness that can be clamped has long since been corrected. Then those elastic vibrations that result in rocking motions of the optics and consequent image motion are to be investigated.

3.1 Vibration Characteristics of Interest

Note that every piece of equipment will have many vibrating mass-spring systems throughout. Only those which contribute to the disturbing image motion are of interest here.

Also, structures often have very little internal damping so that they will magnify vibrations at the resonant frequencies of their dominant mass-spring systems. Almost any structure will have good damping of vibrations above 100 Hz. Vibrations of frequencies from 40 Hz and up usually travel in an acoustic mode (telegraphing) along structural members and are damped out rapidly. Vibrations between 10 Hz and 40 Hz are most often in the range of the natural frequency of supported mass-spring systems and they vibrate in a structural deflection mode.

3.1.1 Mounting Natural Frequency Specified

Stiffness designs often specify the lowest natural frequency that should be used for mounting heavy items. Mounting stiffnesses with natural frequencies between 40 Hz and 70 Hz are considered good, and above 70 Hz are rare and difficult. Mountings of 10 Hz to 20 Hz are considered poor; 20 Hz to 30 Hz marginal; and 30 Hz to 40 Hz are usually acceptable.

3.1.2 Internal Damping Lower at Low Natural Frequencies

The lower the natural frequency, the less internal damping there is in ordinary structure. In fact, for mounting frequencies below 30 Hz, special damping provisions usually must be provided if the elastic motion is damaging to the equipment function.

3.1.3 Low Natural Frequencies Must be Cured

The result of the foregoing is that only those deflections which cause image motion need be considered and cured. If the motions are below 30 Hz, then the structure is too elastic and must either be stiffened or damped, or both.

3.2 Instrumentation

The instrumentation furnished by the contractor includes excitation units, pickup units, motion transducers, an oscilloscope, and an oscillograph recorder. Several techniques need be used to discover the mode of the disturbing vibration and to locate the source of the dominant elastic deflections allowing the rocking motion of the optics.

3.2.1 Geophone and Accelerometers

Inputs at the floor and base of the equipments will be monitored with low frequency (4-1/2 Hz) geophones. As pickups such as geophones and accelerometers measure vibrations in reference to inertial space, they can only be used for input information where relative motion measurements are not necessary. Using inertial detectors for internal equipment measurement can result in great confusion as motions with respect to inertial space are not necessarily significant to image motion which is the result of relative deflections of the optical system.

3.2.2 Deflection Measurements

Deflection measurements can be made with transducers such as LVDT's, strain gauges, or special phonograph needle type pickups. All of these measure translational motions. The magnitude of the motion determines the type of pickup used. Motions from .01 inch up to 1/2 inch are measured with LVDT's. Motions of .0001 inch to .01 inch are measured with the phonograph needle type device. Note that the contractor developed this device a number of years ago for use in his Microseismic equipments that are used in the nondestructive testing of concrete structures. Motions below .0001 inch are measured with strain gauges. We are mostly interested in the .0001 inch to .01 inch range. Care must be used to avoid affecting the measurement with the weight or pressure of the transducer. Also, most of the offending motions are rotational, which requires great care in the placement of the transducer and interpretation of the measurement. Note that the transducers will generally be measuring motions between two parts of the device and this causes further complication in interpretation as both parts may be moving, each influenced by its own elastic system.

3.2.3 Angular Motion Measurements

As most of the motions of interest are angular deflections, applying small mirrors to the offending structure will show up rocking motions by reflecting collimated light on a wall or screen. The excursion of the reflected spot of light is an excellent measure of the angular motion. Depending on the mounting of the light source, the spot motion usually will represent the summed angular motions of the whole device and not relative motions. By judicious use of the motion transducers and the mirrors, insight into the dominant offending motions can be achieved. Once this is understood, a cure can be worked on.

3.2.4 Vibration Excitation

The contractor will use forced vibrations, both continuous sinusoid and shock input, for analysis. The so-called Hertzian die-out from a shock input is fully as revealing as the response to a sinusoid sweep.

3.2.5 Recording Vibration Levels

The various pickups and transducers will be calibrated at the contractor's plant for vibration amplitude. The oscilloscopes and oscillographs have internal frequency standards so that vibration frequencies can be determined and compared. The oscilloscope will be used for initial survey activity and the oscillograph will be used to record significant data after the transducers have been properly placed.

4.0 Discussion of Correction Techniques

The correction techniques include stiffening the structure, adding internal damping by bolting on patches or beam caps, adding external damping, adding counterbalances to reduce rocking caused by unbalanced mass forces, or isolating the equipment from external vibrations. The appropriate combination of the above methods can only be chosen after the cause of the image motion is understood.

4.1 Load Path Analysis

Final insight into the offending elastic deflection is achieved by a careful load path analysis of the supporting structure. Estimating the vibratory effect of the various mass-spring systems along the load path will indicate direction of the cure. As a result of this analysis, additional measurements may be made and relative deflections under special static forces may be measured to confirm the conclusions.

5.0 Proposed Work Plan

It is proposed that a quick overall view of the equipment be provided and a preliminary indoctrination into the problems of each equipment be given the contractor's personnel at the customer's facility. From this review and discussions, a Program Plan will be devised by the contractor to cover each of the equipments chosen by the customer to be analyzed. The customer will establish his desired priority, which will be adhered to insofar as possible.

5.1 Working Area and Access

The contractor will be given space to work and, in sequence, access to the equipments for investigation. The contractor will provide the instrumentation needed for the work. Each type of equipment will be investigated in turn and the mode of vibration and offending structure determined and a cure devised if feasible.

5.2 Operational Assistance and Indoctrination by Customer Personnel

Customer personnel will assist in operating the equipment and provide indoctrination of the contractor in the operational problems with the equipments. Practical cures of the vibration difficulties can only be devised if the operation and uses of the equipment is fully appreciated by the contractor.

5.3 Data and Report Formats

The contractor will devise appropriate data formats so that the information will be recorded and preserved in a consistent manner useful to the purpose. Report formats will be devised that will provide a coherent presentation of the results and conclusions.

5.4 Demonstration of Vibration Cures

Whenever a feasible vibration cure has been devised for one of the equipment types, demonstration hardware will be fabricated at the contractor's plant and installed on the equipment in the customer's facility. Using the appropriate instrumentation and vibration excitation equipment, the effectiveness of the vibration cure will be measured and demonstrated.

5.5 Final Report and Recommendation

A final report will be submitted giving a comprehensive review of the investigation and submitting the significant data. The evaluation of the effect of vibration on pointing accuracy will be given. The details of the practical vibration cures for each of the equipments

5.5 Final Report and Recommendation (Contd.)

will be given and recommendations made. The results of the demonstration and measurement of the vibration cures will be given. Criteria for the design and installation of high magnification optical systems to minimize the effect of vibration will be provided.

It is also proposed that the program be reviewed with the customer in a final technical review meeting after the submission of the final report.

5.6 Work Statement

5.6.1 Phase 1

1. Review customer equipment for vibration limitations.
2. Review potential problem areas in the equipment.
3. Select five types of instruments for test. Generate a Project Plan for further investigation on the selected types.
4. Perform vibration analyses including dynamic and relative motion tests on the five selected types as appropriate.
5. Report on the extent of the vibration problems and establish the disturbing levels.
6. Prepare and submit cost estimates and detailed plans for Phase 2.

5.6.2 Phase 2

1. Perform detailed analysis of equipment identified in Phase 1 and determine extent and type of fix practicable.
2. Prepare trade off analyses on cost of fix versus type of fix and extent of improvement to be expected.
3. Demonstrate cure on a selected type of equipment.
4. Generate vibration specification criteria for use in future equipment procurement.
5. Recommend a practical vibration environment for high resolution equipment.

5.7	Deliverable Items and Schedule, Phase 1	Schedule
1.	Preliminary investigation and meetings	During first 3 weeks
2.	Selection of 5 instruments and Project Plan for each equipment	During 3rd through 8th weeks (Submit as completed)
3.	Letter Progress Reports	Monthly
4.	Vibration Analyses of Selected Equipment (in sequence for each equipment)	Beginning 5th week Final 12th week
5.	Final Report	16th week
6.	Final Technical Review Meeting	18th week

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